



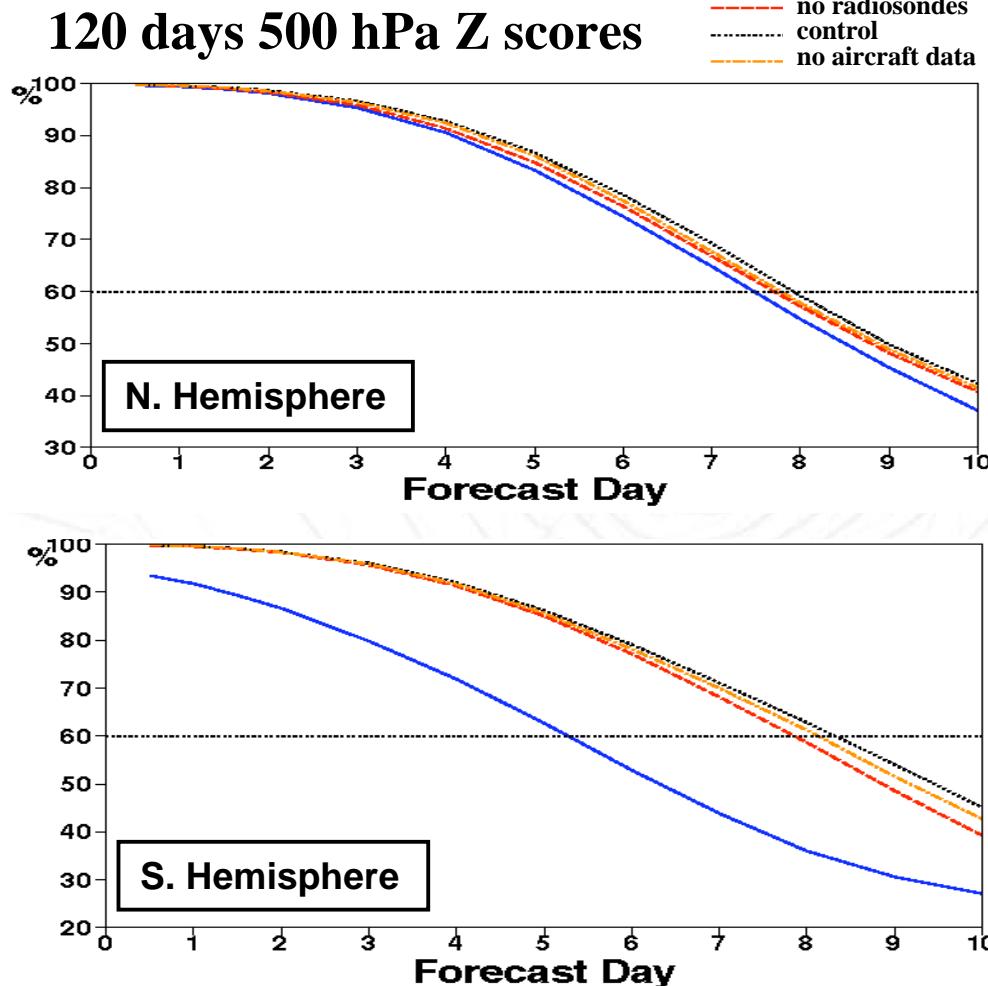
## Satellite Observations of the Global Water Cycle

# Prediction and Assimilation Challenges (from an ECMWF perspective)

**M. Drusch, E. Andersson, A. Agusti-Panareda, G. Balsamo, P. Bauer,  
J. Berner, R. Buizza, L. Ferranti, G. Kelly, P. Lopez, P. Viterbo  
(ECMWF)**



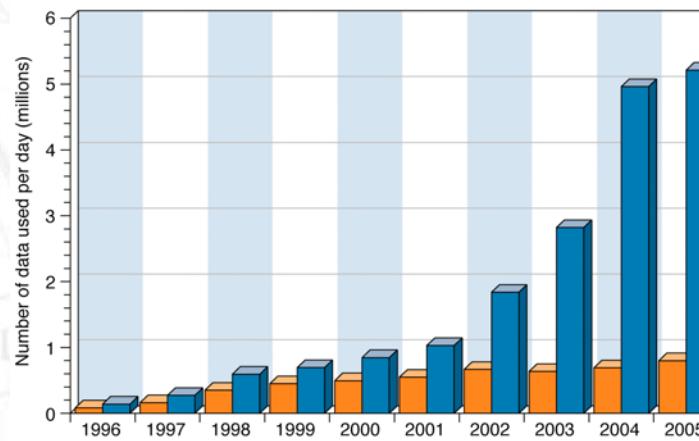
# Is Satellite Data Important for NWP ?



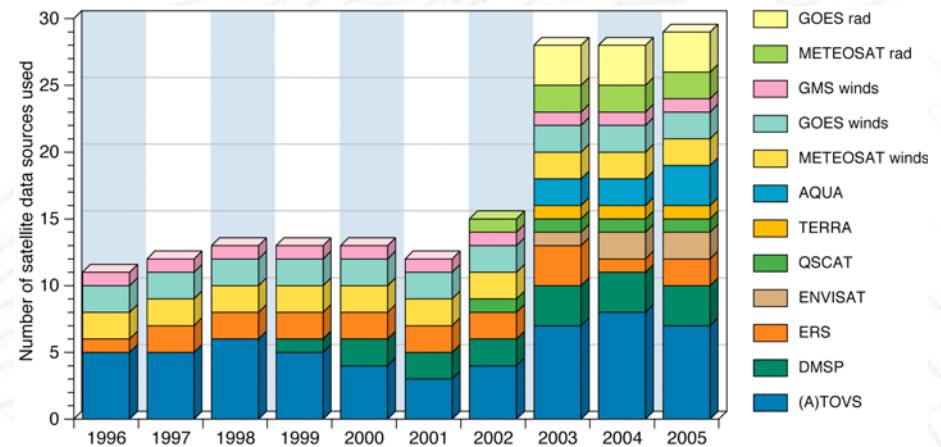
Observing system experiments (OSEs) aimed at measuring the impact of different types of observation routinely confirm that **satellite data is now the single most important component** of the global observing network for NWP.



# Satellite Data Statistics



Total  
Conv + sat winds



- ~4 Mio. Satellite observations are used in the atmospheric 4D-Var analysis.
- Over land, the application of satellite data is limited to the upper troposphere and the stratosphere.
- Apart from the NH NESDIS snow cover product, no satellite observations have been used in the land surface analysis.



# Outline: Selected Results from RD

1. Assimilation of TMI derived soil moisture over the Southern US  
Initialization using satellite derived soil moisture, deterministic short-range forecast system, soil moisture analysis and the impact on weather parameters.
2. AMMA (African Monsoon Multidisciplinary Analysis)  
offline soil moisture initialization experiment  
, Offline soil moisture initialization using satellite derived precipitation, deterministic short-range forecast system, soil moisture and precipitation.
3. Assimilation of rain-affected radiances from TMI / SSMI  
1DVar+4DVar atmospheric analysis, deterministic short-range forecast, total column water vapor
4. Stochastic physics / initial perturbations in the Ensemble Prediction System  
EPS, medium-range, soil moisture initialization, ensemble spread, ROC scores
5. The European draught 2003 – Experiments with the Seasonal Forecast System  
EPS, monthly / seasonal forecast system, soil moisture initialization, ensemble mean

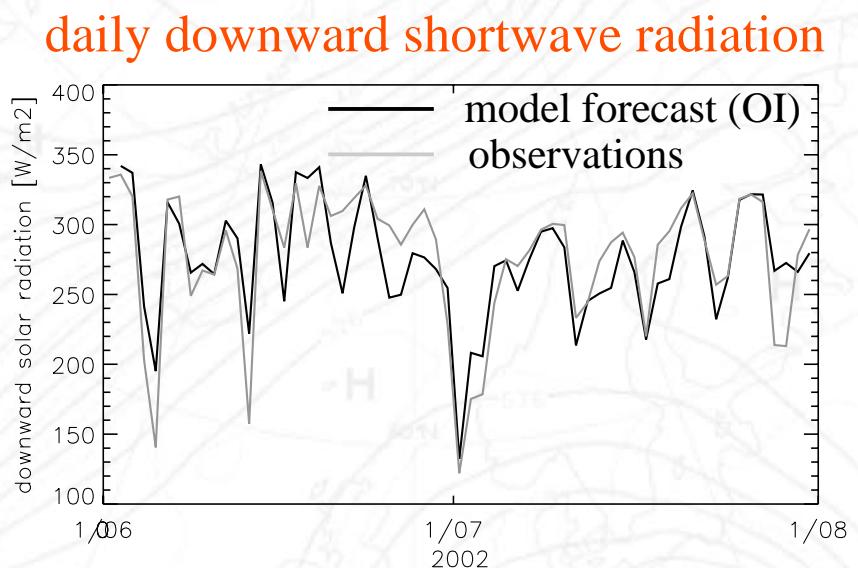
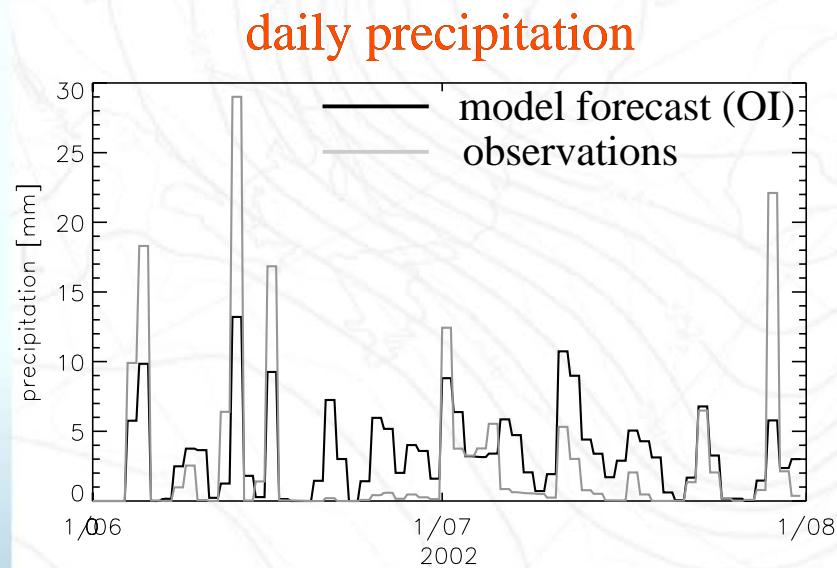
All experiments make use of the current operational forecast system:

- in 1) – 3) satellite observations directly related to hydrological parameters have been added
- 4) and 5) are soil moisture impact studies



# 1. Soil Moisture Assimilation over Land: Experiments with the TMI data set [Gao et al.]

Validation of forcing data: Area averages for Oklahoma (72 stations)



## total amount of rainfall:

June	87.3 mm model	on
	87.8 mm observations	on
July	110. mm model	on
	79. mm observations	on

19 days  
9 days  
26 days  
20 days

Correlation  
Bias

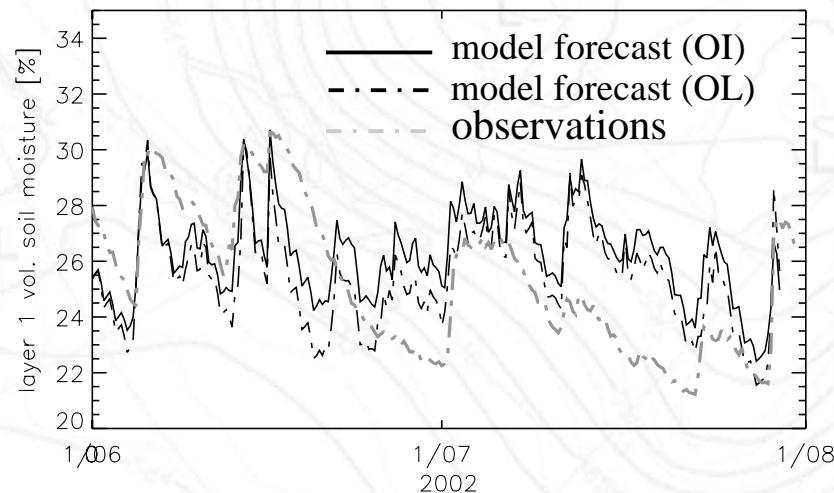
: 0.85  
: - 0.7 Wm<sup>-2</sup>



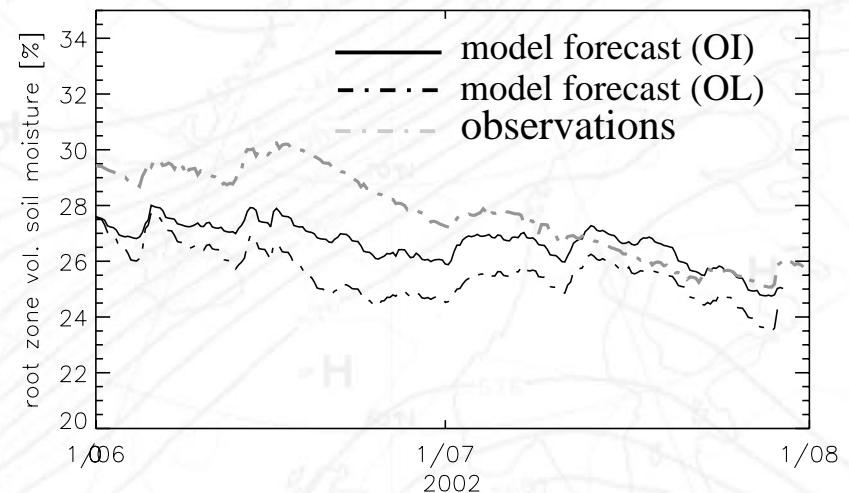
# 1. Soil Moisture Assimilation over Land: Experiments with the TMI data set [Gao et al.]

Validation of soil moisture: area averages for Oklahoma (72 stations)

surface soil moisture



root zone soil moisture



- Too quick dry downs (model problem).
- Too much precip in July (model problem).
- Too little water added in wet conditions (analysis problem).
- NO water removed in dry conditions (analysis problem).

- Precipitation errors propagate to the root zone.
- Analysis constantly adds water.
- The monthly trend is underestimated.

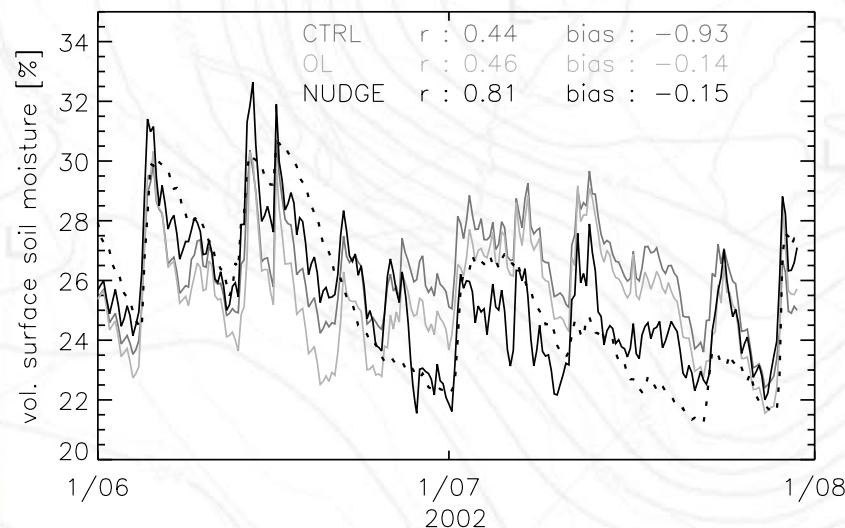
The current analysis fails to produce more accurate soil moisture estimates,  
BUT results in more accurate low level temperature and humidity fields.



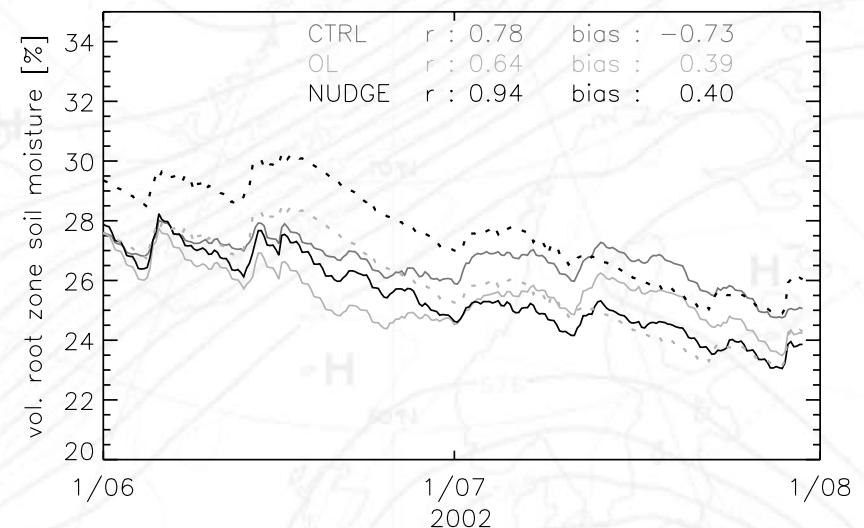
# 1. Soil Moisture Assimilation over Land: Experiments with the TMI data set [Gao et al.]

Results from the TMI nudging experiment: area averages for Oklahoma

surface soil moisture



root zone soil moisture



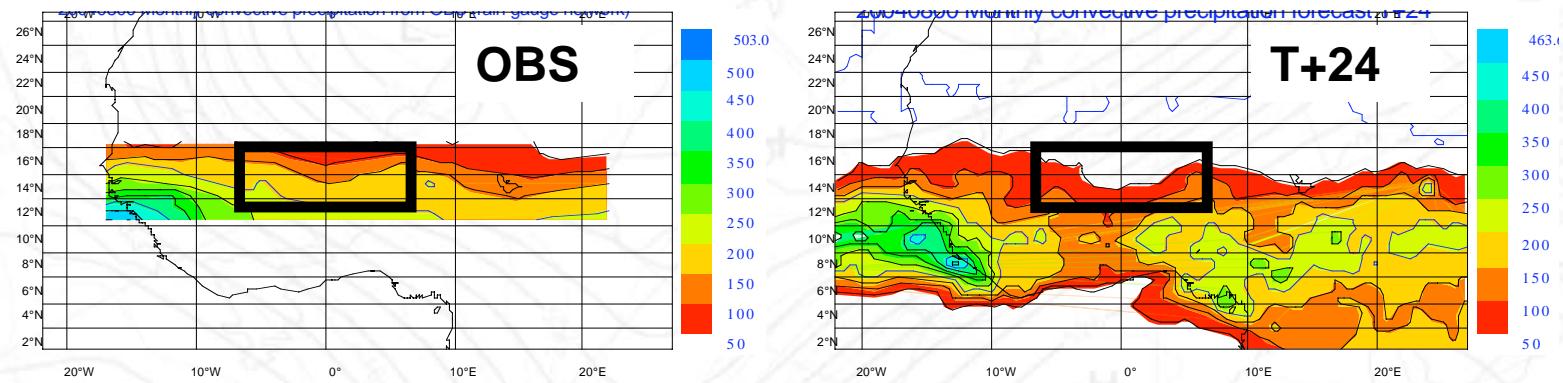
- Nudging / satellite data remove water effectively and produce a realistic dry down.
- Nudging the satellite results in the most accurate surface soil moisture estimate.

- The information introduced at the surface propagates to the root zone.
- The monthly trend is well reproduced using the nudging scheme.

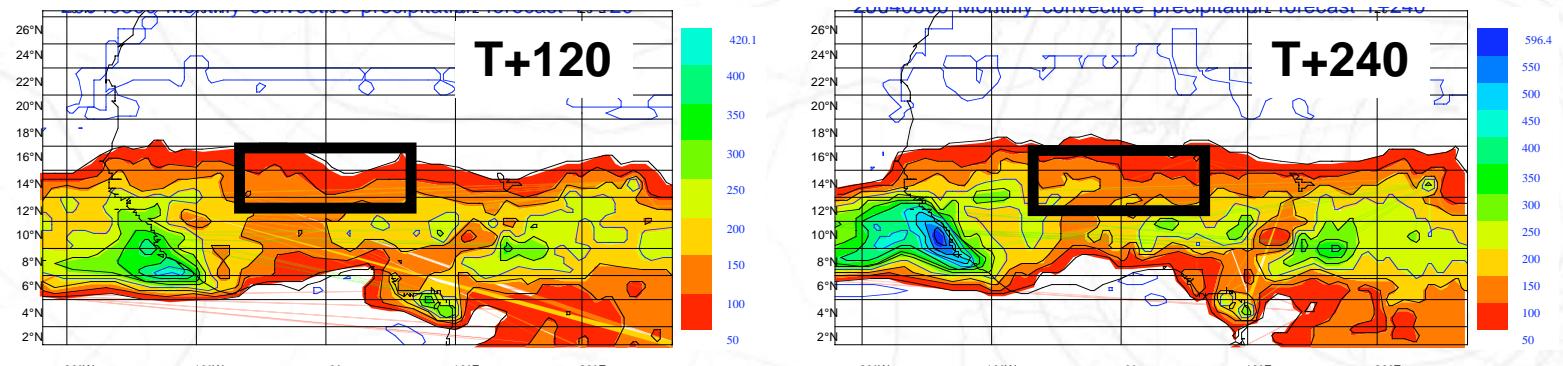
Satellite derived soil moisture improves the soil moisture analysis and results in the most accurate estimate, BUT the impact on the atmosphere is slightly negative.



## 2. AMMA Soil Moisture Initialization Study: Precipitation



monthly (convective) precipitation for August 2004 [mm]



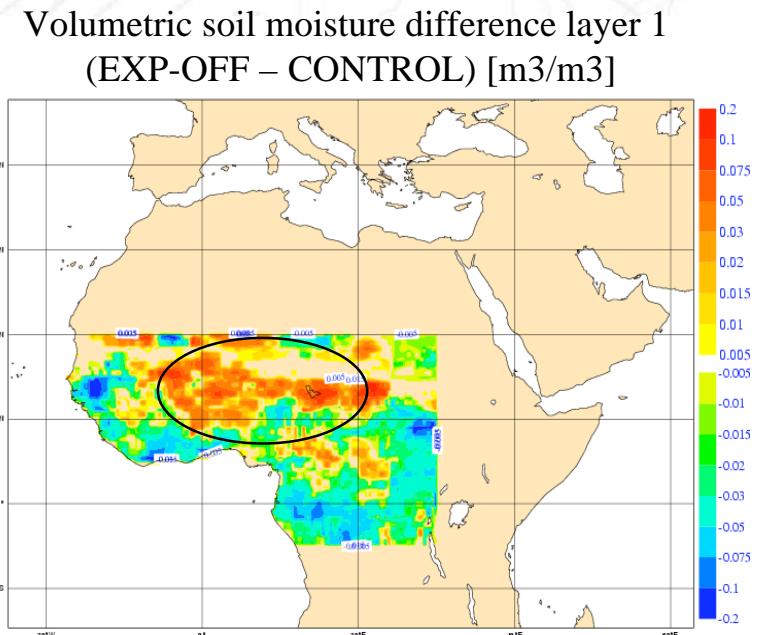
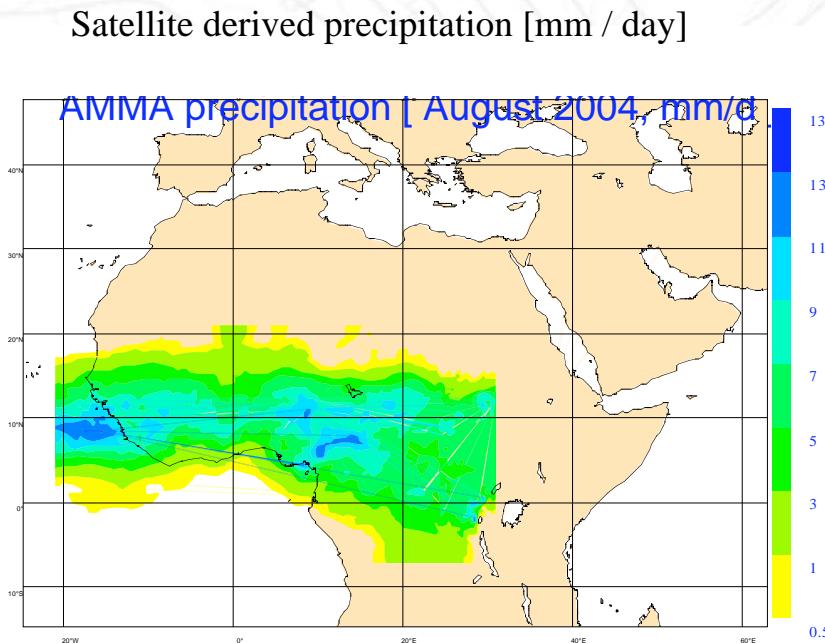


## 2. AMMA Soil Moisture Initialization Study: Offline Initialization Experiments

Impact study based on two experiments (cy30r1, T511, L60) for July & August 2004.

**CONTROL:** Forecast initialized with soil moisture from the operational forecast system.

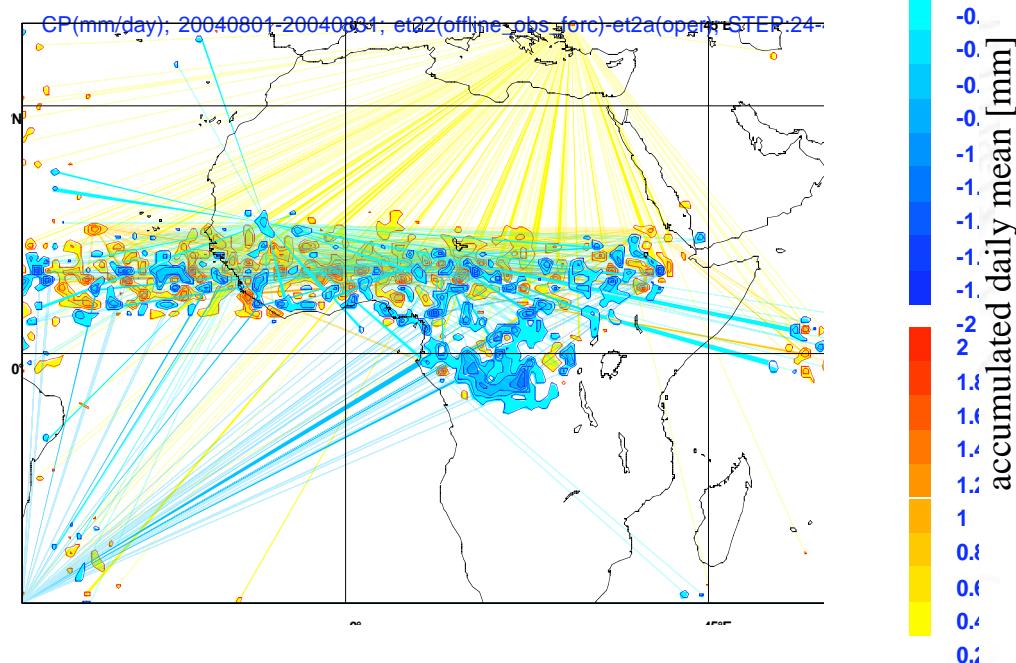
**EXP-OFF :** Forecast initialized with ‘optimal’ soil moisture fields obtained from satellite derived rainfall (EPSAT: MSG, TRMM & GPCP) and the offline land surface model (TESSEL).



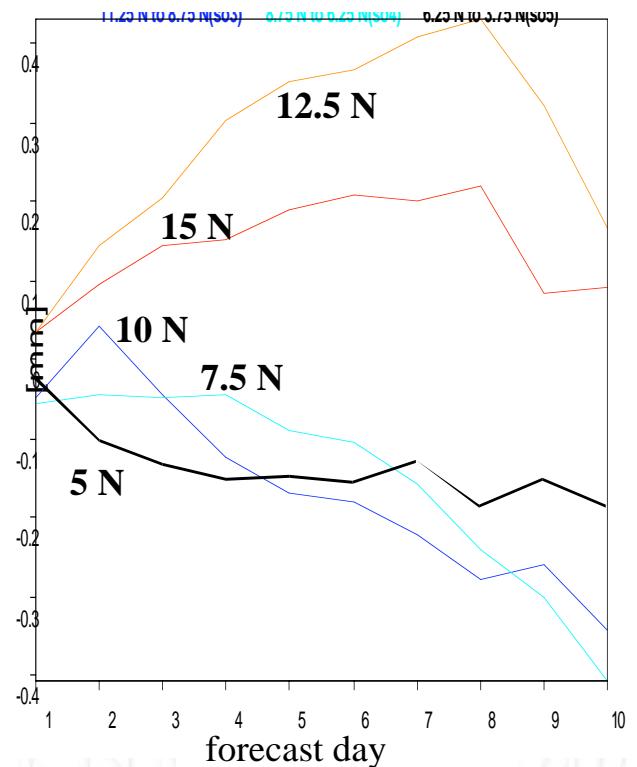


## 2. AMMA Soil Moisture Initialization Study: Precipitation Forecasts

convective precipitation  
(EXP-OFF – CONTROL)  
[mm / day; fc 48 – fc 24]



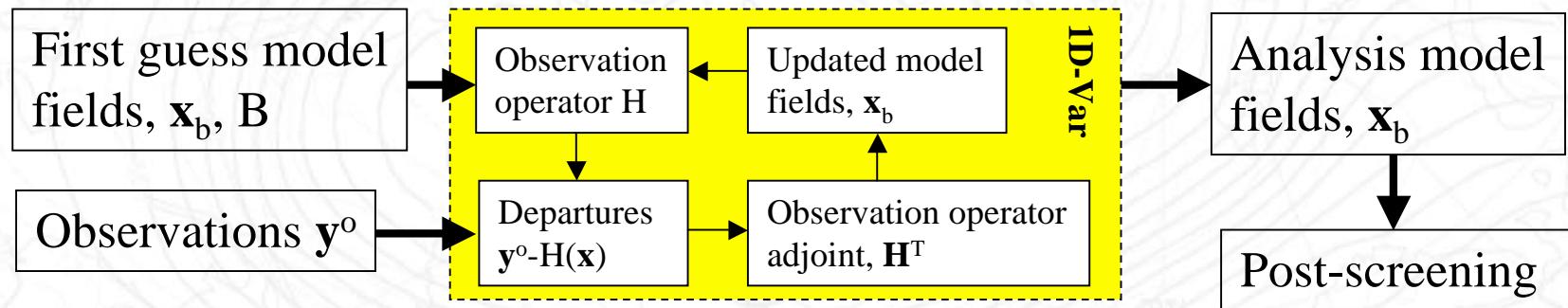
convective precipitation  
(EXP-OFF – CONTROL)  
[ $15^{\circ}\text{W}$ - $40^{\circ}\text{E}$ ]



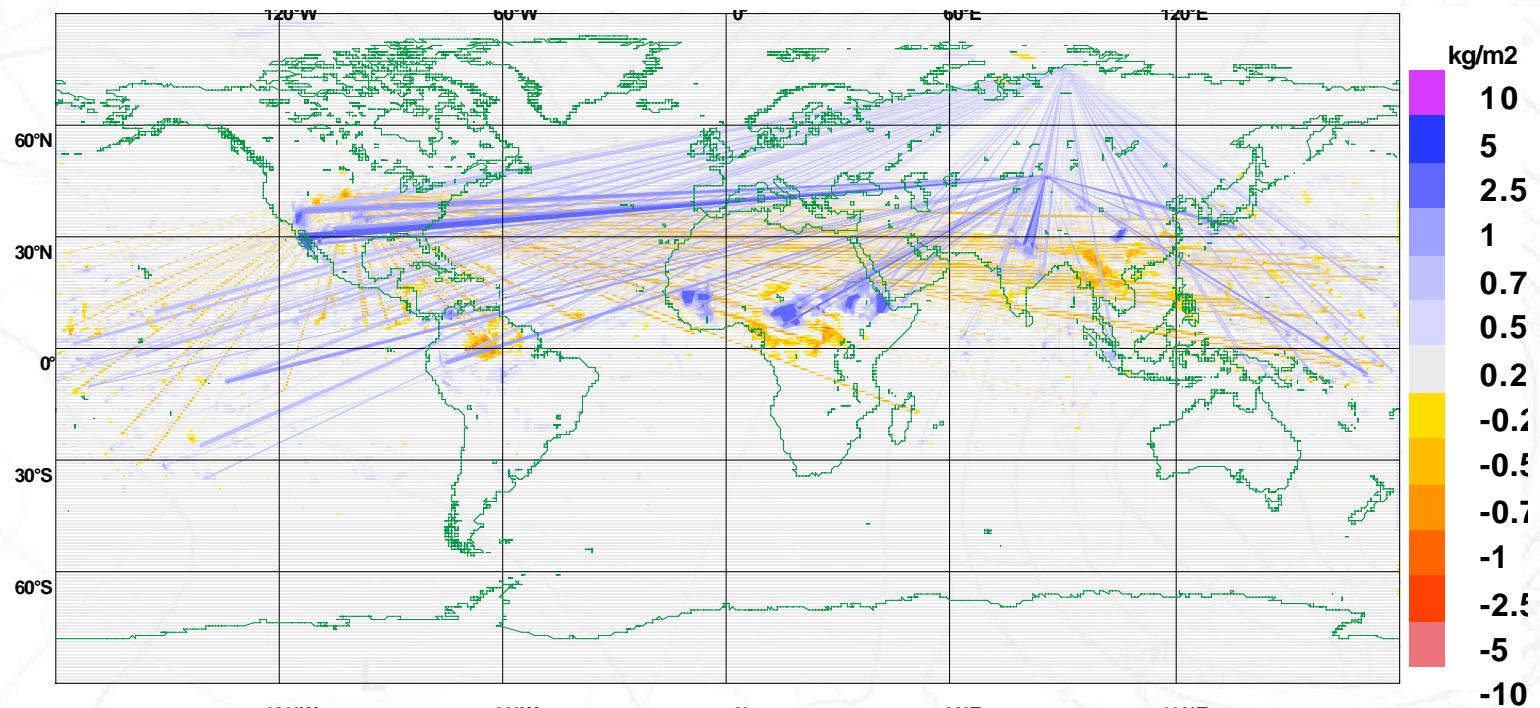
- ECMWF model places the precipitation belt over West Africa too far south.
- There is a northward drift of this precipitation belt with increasing forecast range.
- There is a general increase in CAPE and convective precipitation over the Sahel. The improvement of the precipitation forecast with initial soil moisture from open loop with observed forcing is comparably small. (Dry bias in radiosonde observations!)



### 3. Precipitation Assimilation over Land: TRMM 2A12 Rain Rates



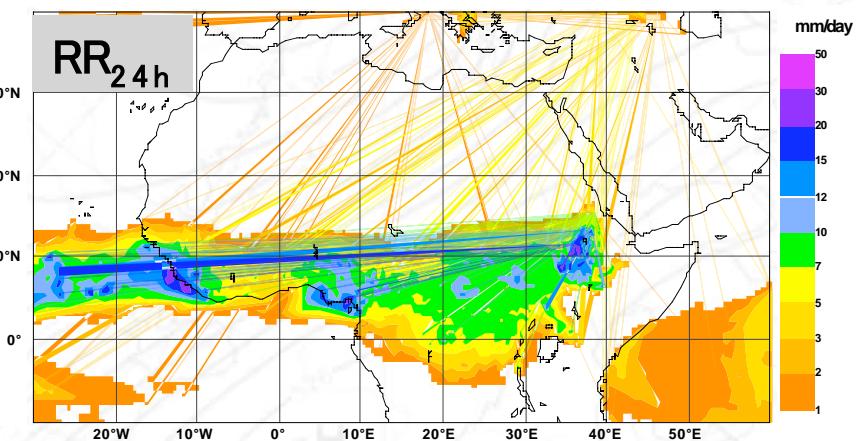
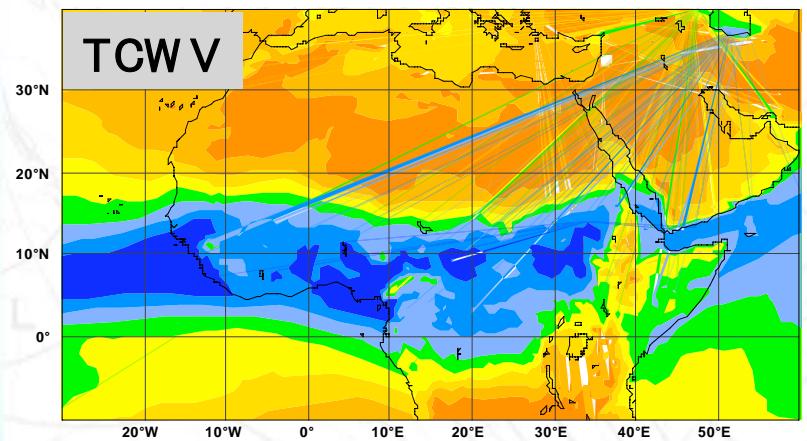
Mean TCWV analysis increments 1-25/07/2006 at 00UTC



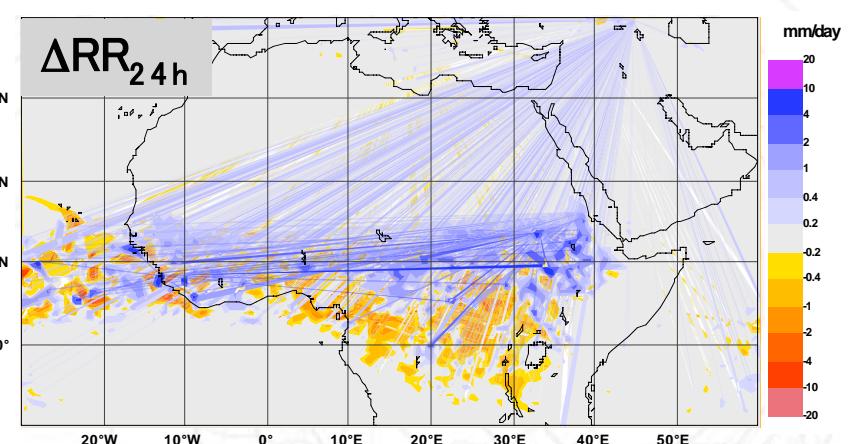
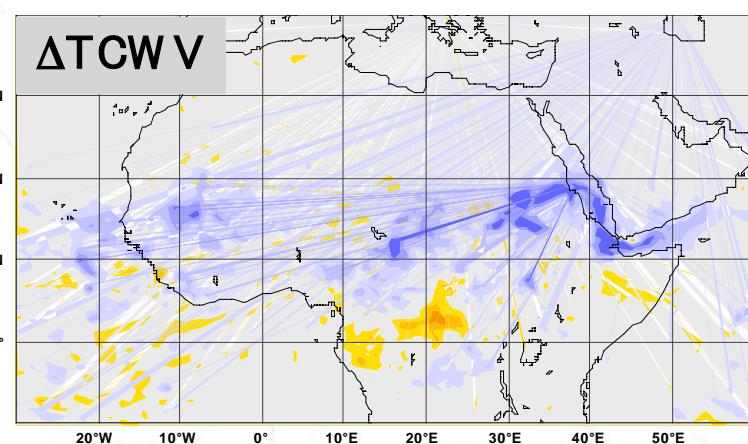


### 3. Precipitation Assimilation over Land: 24-hour Forecast Differences: EXP<sub>TMI</sub> – Control

EXP<sub>TMI</sub>



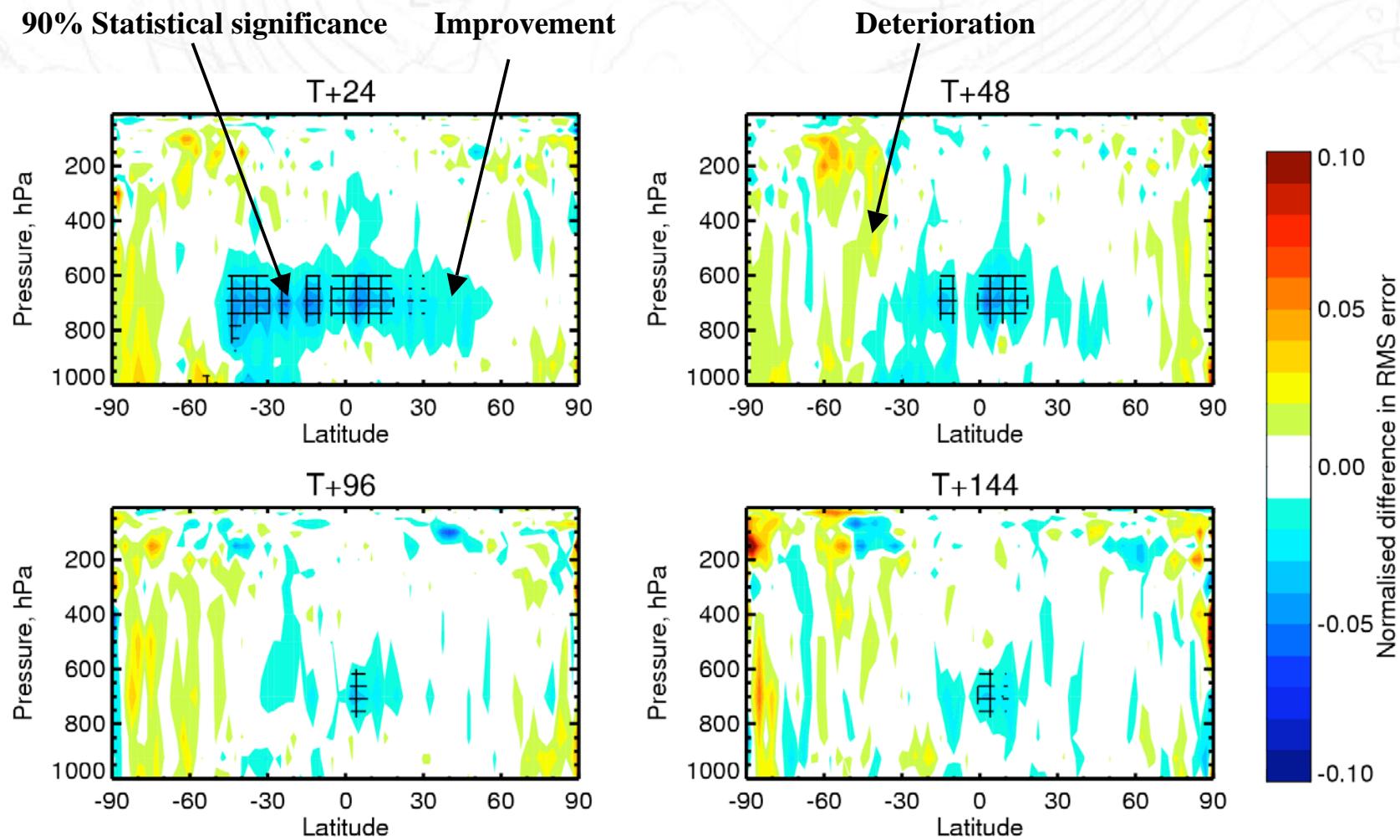
EXPTMI - Control





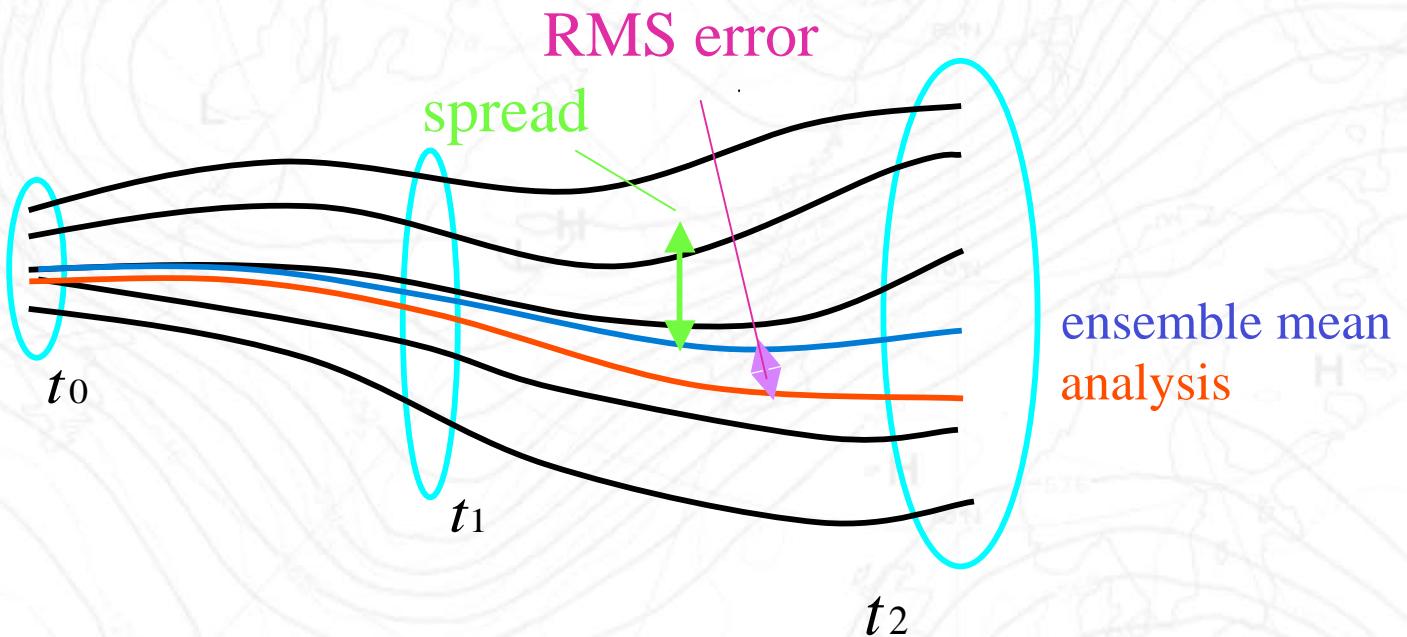
### 3. Operational Precipitation Assimilation over Ocean: Mean Relative Humidity Forecast Score Difference 08-10/2004

Improvements in RMS forecast errors between “Rain” and “No Rain” experiments





## 4. Stochastic Soil Moisture / Initial Perturbations



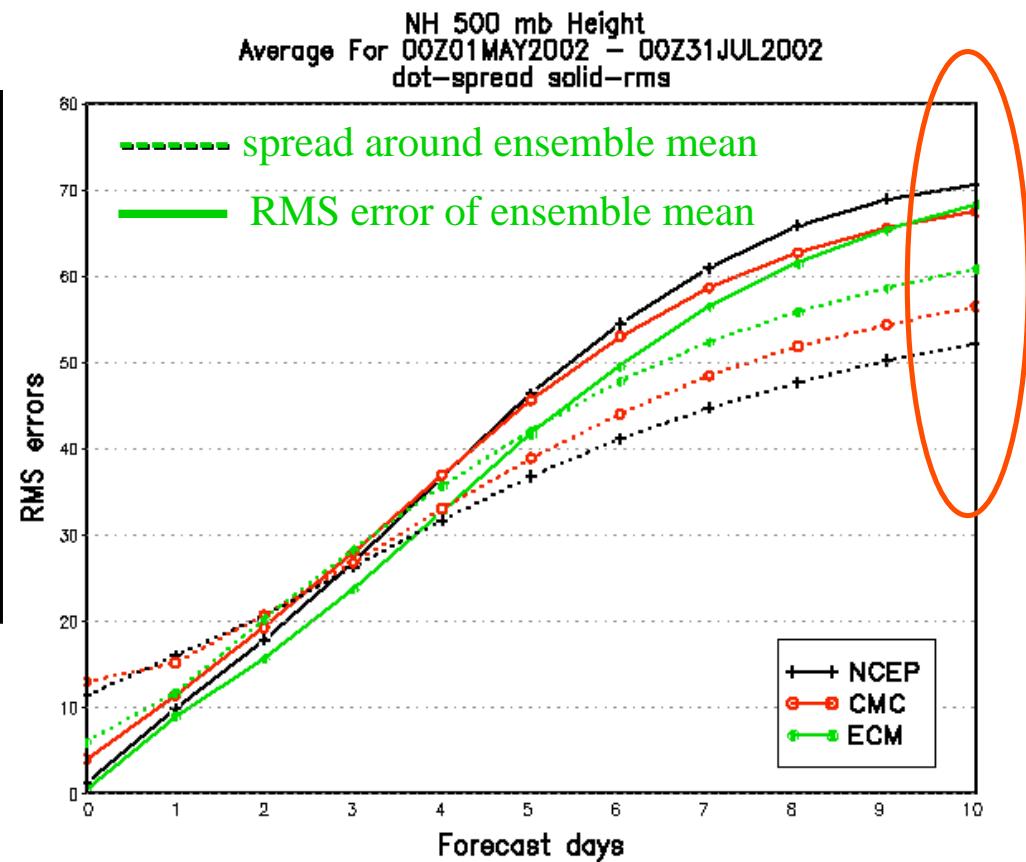
- Represent initial uncertainty by ensemble of states
- Flow-dependence:
  - Predictable states should have small ensemble spread
  - Unpredictable states should have large ensemble spread
- ***Ensemble spread should grow like RMS error***



## 4. Stochastic Soil Moisture / Initial Perturbations

The RMS error grows faster than the spread:

- Ensemble is **underdispersive**
- Ensemble forecast is **overconfident**
- Initial perturbations are chosen artificially large





## 4. Stochastic Soil Moisture / Initial Perturbations

- Perturb soil moisture q:

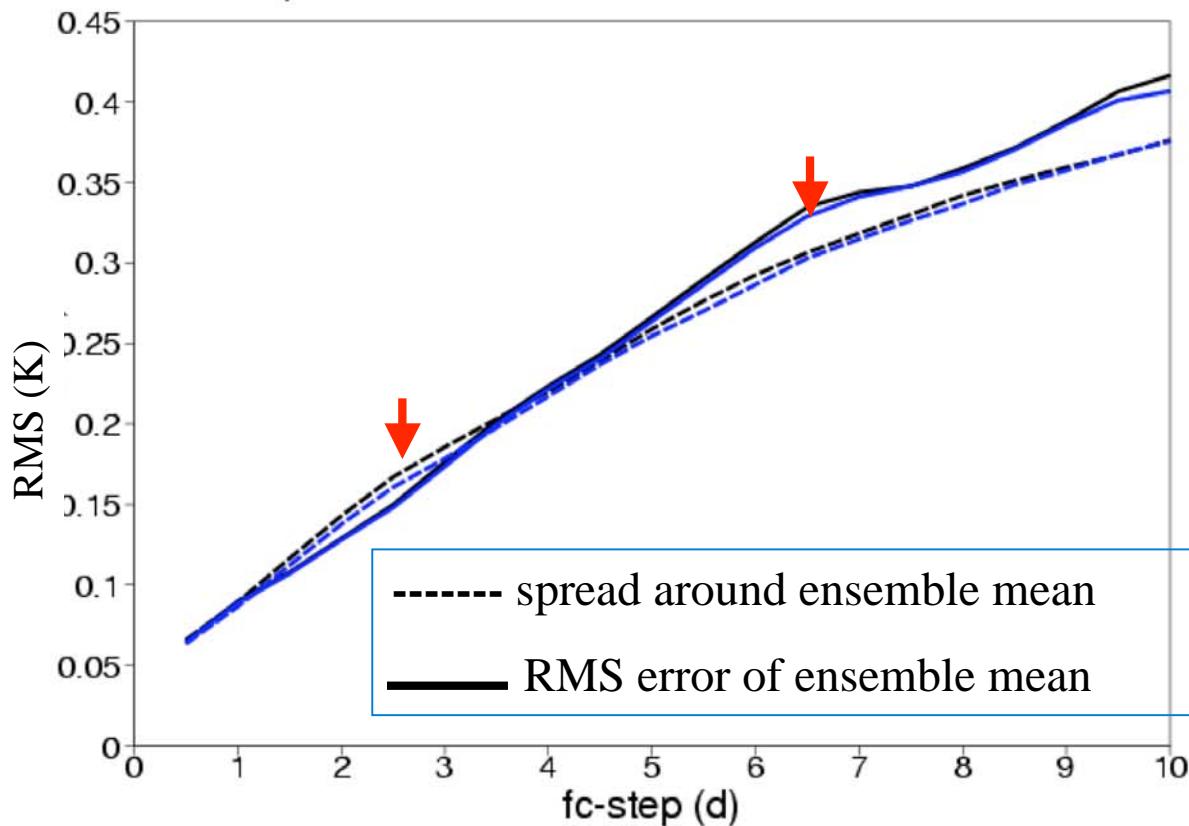
$$\dot{q} = (1 + \varepsilon)D$$

- D prognostic update
- $\varepsilon$  is a stochastic variable, constant over time intervals of 32hrs and over 10x10 lat/long boxes (i.e. local spatial and temporal correlations)
- 10 member ensemble with and without stochastic soil moisture
- 12 cases between May 2004 and April 2005
- Resolution T255L40



## 4. Stochastic Soil Moisture / Initial Perturbations

t850hPa; area: n.hem.mid,  
black: eswk/M0-63LL; blue: evcc/M0-63LL  
solid: RMS error of em, dashed: spread around em  
sample of 12 cases; 2004050100 - 2005041800



No SSM

SSM

Overdispersion of T850 for short forecast ranges is reduced!

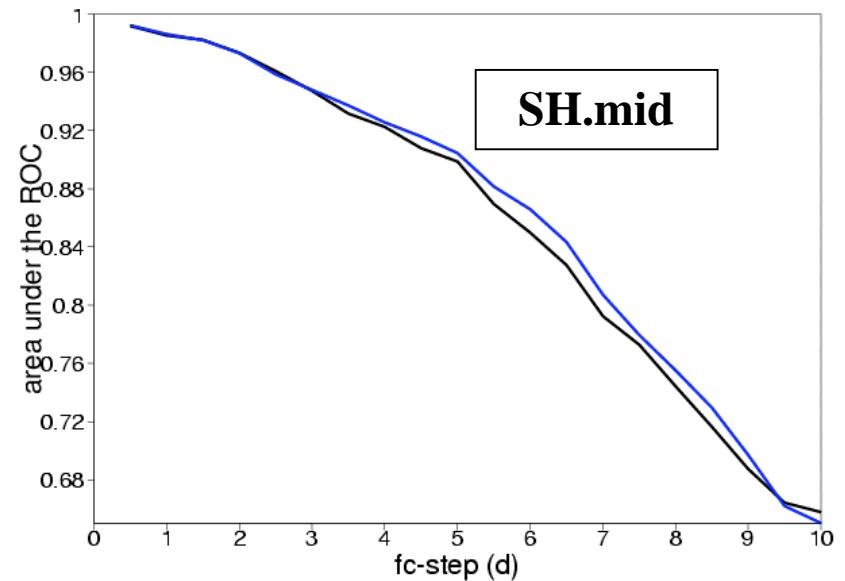
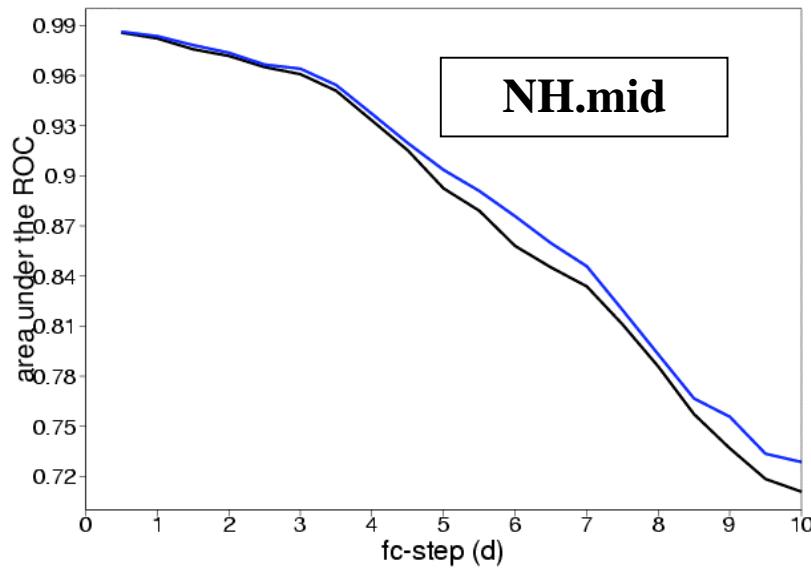
RMS error is slightly reduced!



## 4. Stochastic Soil Moisture / Initial Perturbations

### T850 skillscores (ROC area):

- Large ROC (relative operating characteristics) means more skilful ensemble
- Skill of T850 in SH and NH improved



- SSM can decrease spread (e.g. in NH.mid) although stochastic perturbations were introduced
- SSM increases the skill in the extratropics
- SSM does not perform as well in tropics
- SSM seems to reduce RMS error of ensemble, but: more cases are needed

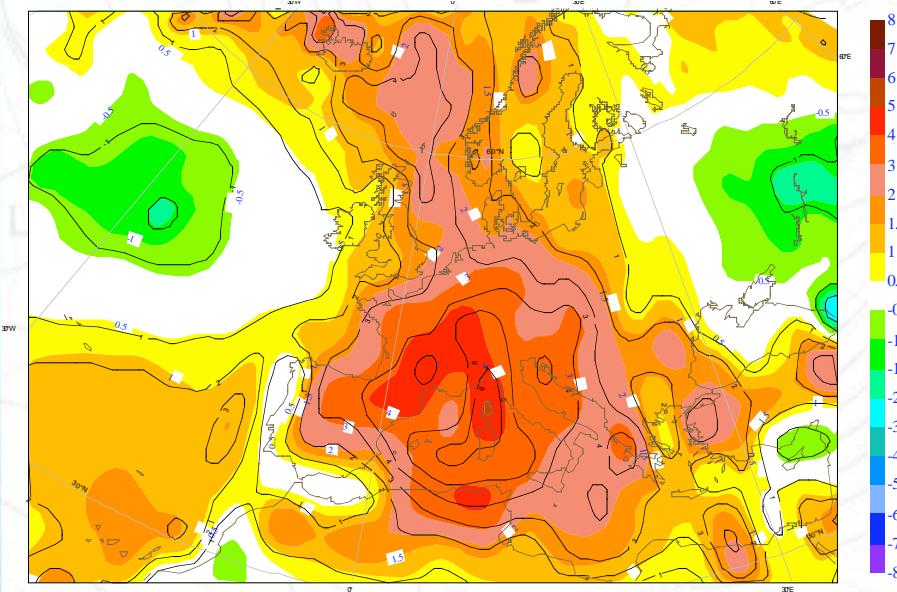


# European Draught Summer 2003: Forecast Experiments with the Ensemble Prediction System

Shading: precipitation anomaly [mm/day]

Contours: Anomalies normalized by  
standard deviation

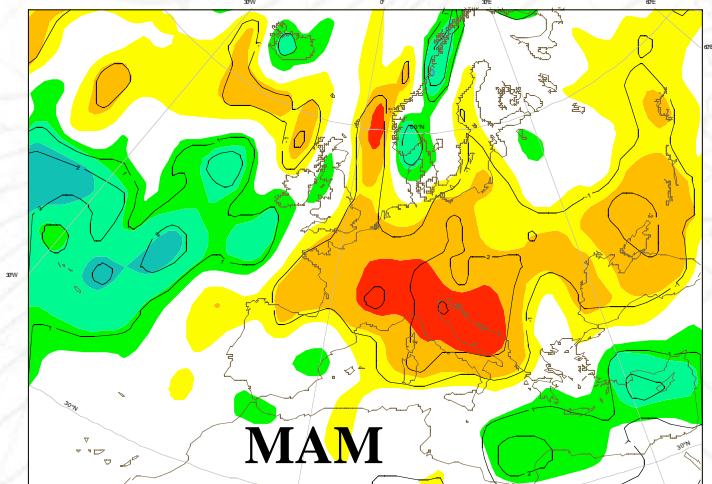
Reference: GPCP monthly means 1979-2000



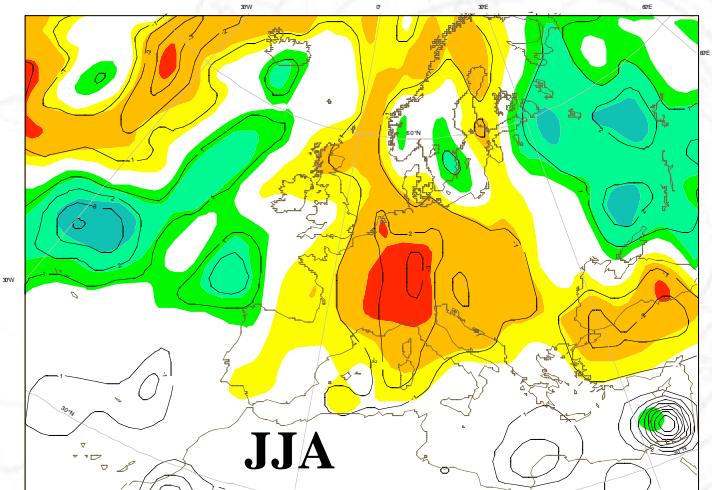
Shading: 2 m temperature anomaly JJA [K]

Contours: Anomalies normalized by  
standard deviation

Reference: corrected ERA-40 1958-2001



MAM



JJA



# European Draught Summer 2003: Forecast Experiments with the Ensemble Prediction System

**Each ensemble:** 9 members initialized  
28 May to 5 June  
Cy 25R4, T95 (~200 km), 40 levels

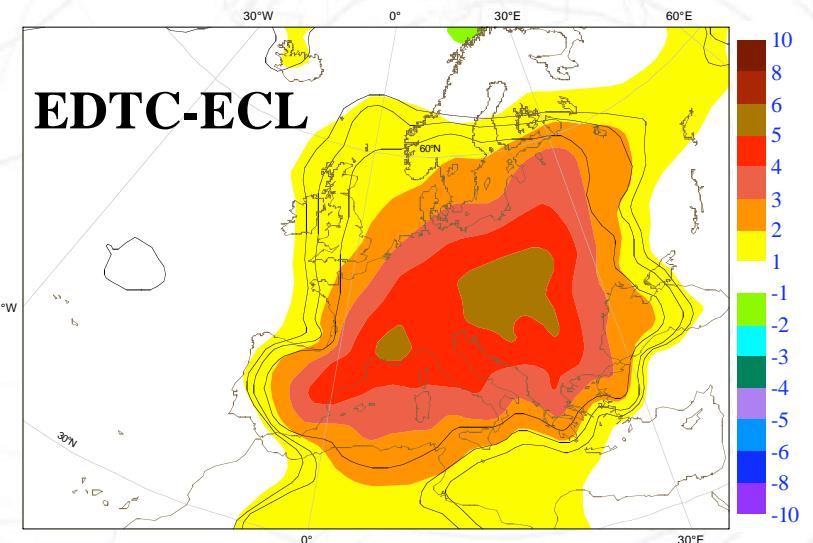
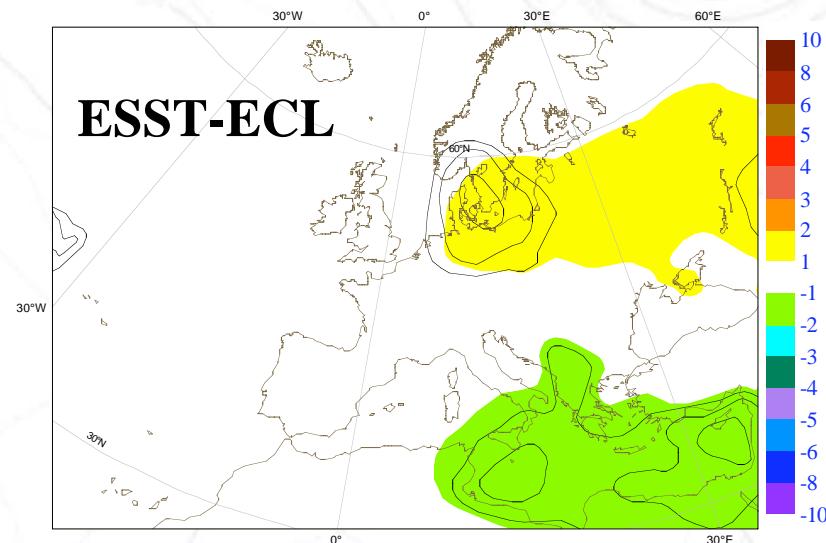
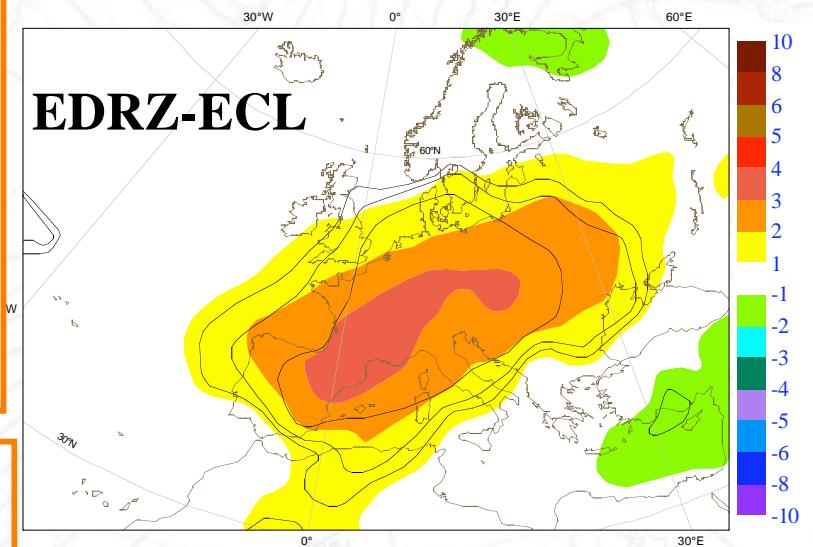
**ECL:** ‘operational’ soil moisture, clim. SST

**ESST:** ‘operational’ soil moisture, obs. SST

**EDRZ:** ‘dry’ root zone (SWI 25%), obs. SST

**EDTC:** ‘dry’ soil column (SWI 25 %), obs. SST

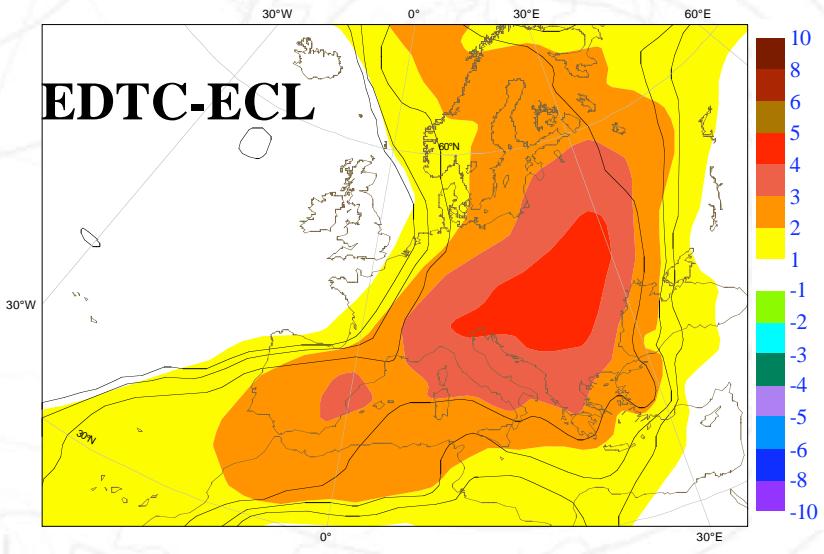
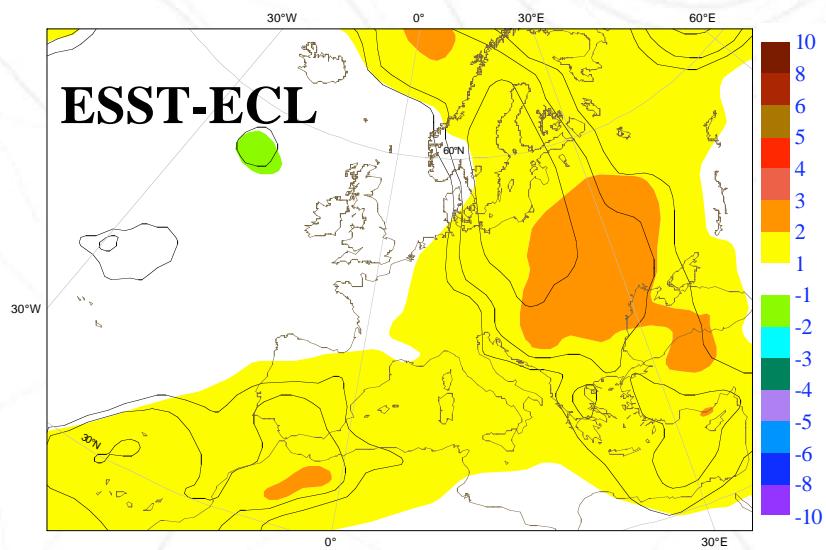
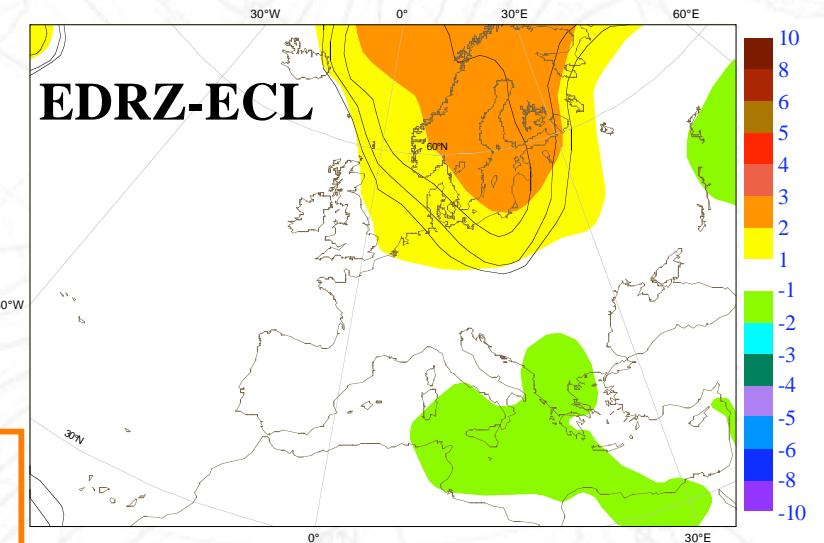
**ensemble mean differences for month 2  
(July) for 850 hPa temperatures**





# European Draught Summer 2003: Forecast Experiments with the Ensemble Prediction System

ensemble mean differences for month 3  
(August) for 850 hPa temperatures





## Conclusions

Land surface hydrology is important for NWP and environmental monitoring. Comparing individual satellite derived data sets with model fields is a first step. Eventually, different types of observations should be combined with a modeled first guess.

1. Introducing new observations to the DA / forecasting system is the most efficient way to improve the model (and the analysis):



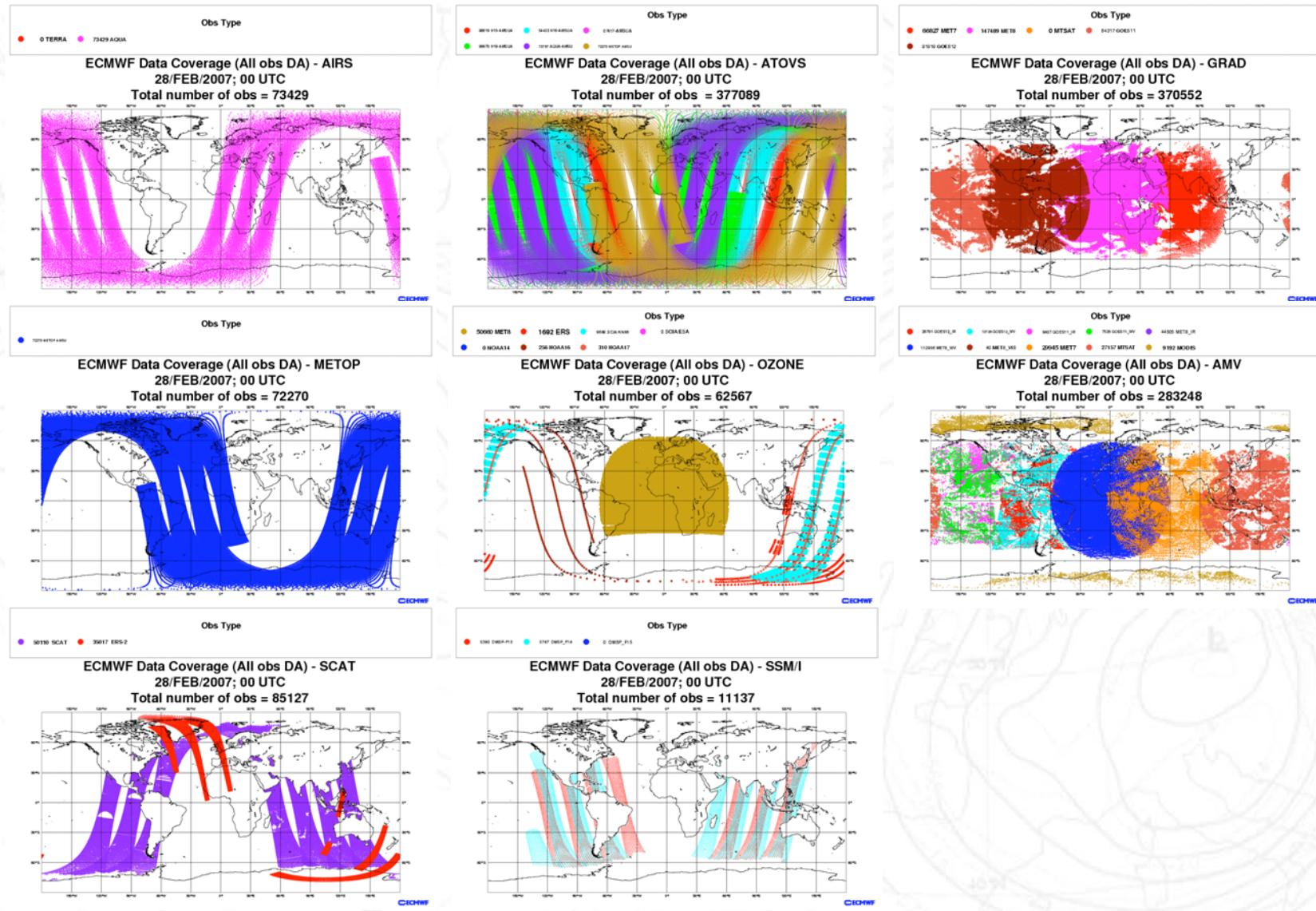
2. Quality control is a key issue!

Temporal and spatial consistency is only one aspect; different observation types need to be consistent as well. DA provides the framework ...

3. The 'gold standard' could (will) be re-analyses including observations (closeley) related to the water cycle. Satellite data have to be available in NRT for the operational system (monitoring) before they can be used in re-analyses (at ECMWF).
4. New verification standards (and data sets) are needed (500 hPa geopotential height is not enough). NWP centres should include precipitation, soil moisture, 2m T, cloud coverage ...



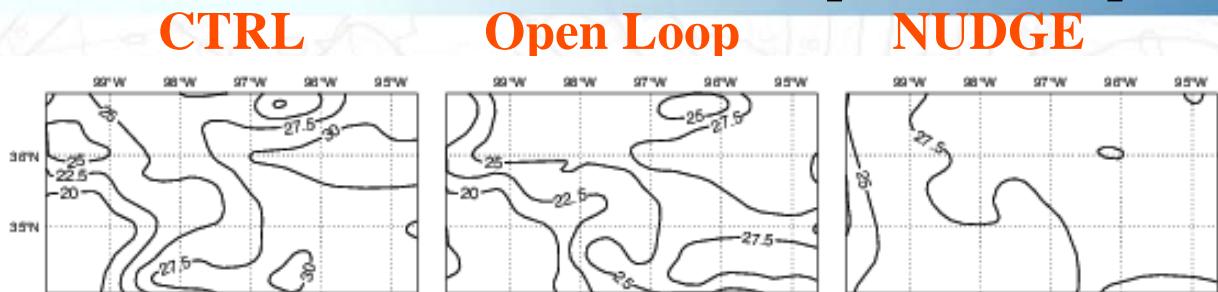
# Satellite Data Statistics



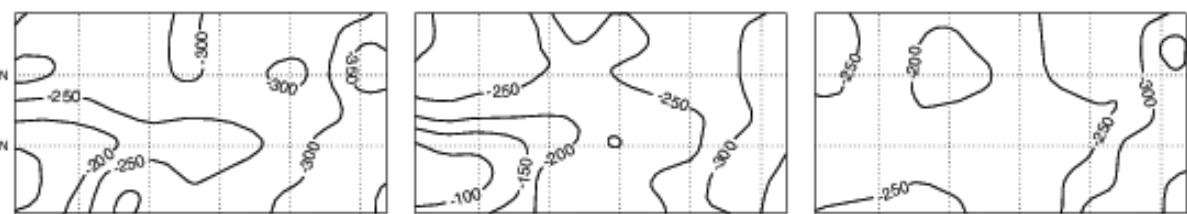


# Soil Moisture Assimilation over Land: Experiments with the TMI data set [Gao et al.]

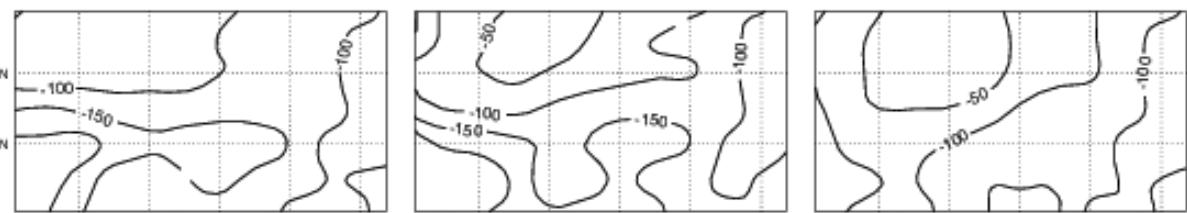
surface soil moisture  
[%] at 18 June, 12 UTC



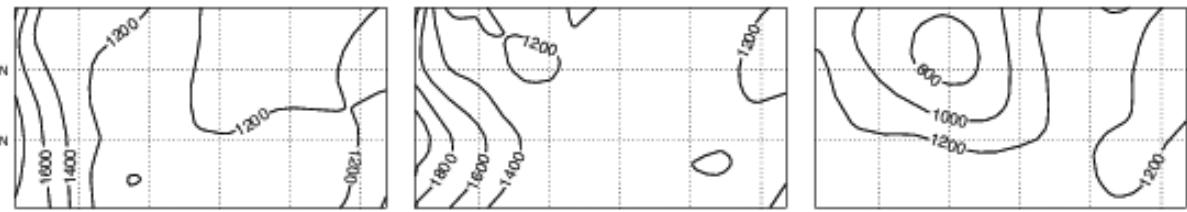
latent heat flux [ $\text{Wm}^{-2}$ ]  
mean over 18 June  
12 UTC to 00 UTC



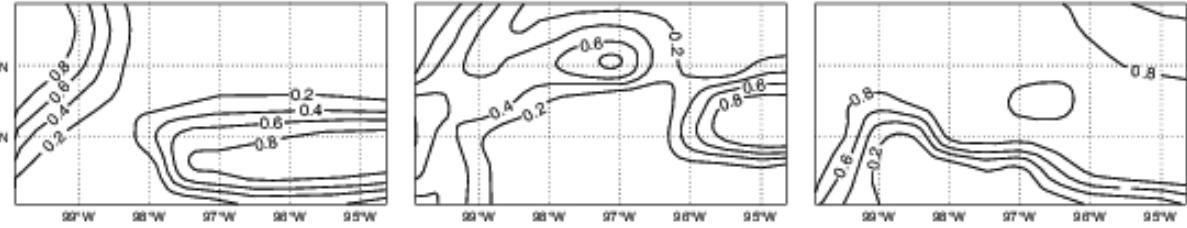
sensible heat flux [ $\text{Wm}^{-2}$ ]  
mean over 18 June  
12 UTC to 00 UTC



planetary boundary  
layer height [m]  
at 19 June 00 UTC



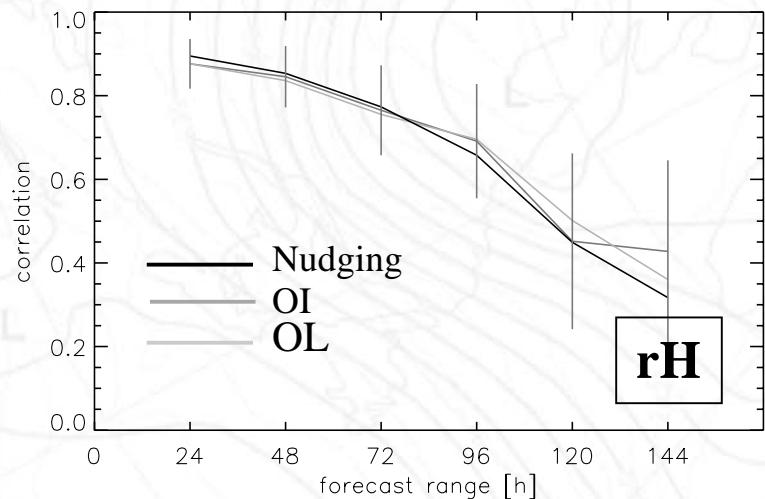
total cloud coverage  
[0-1] at 19 June 00 UTC



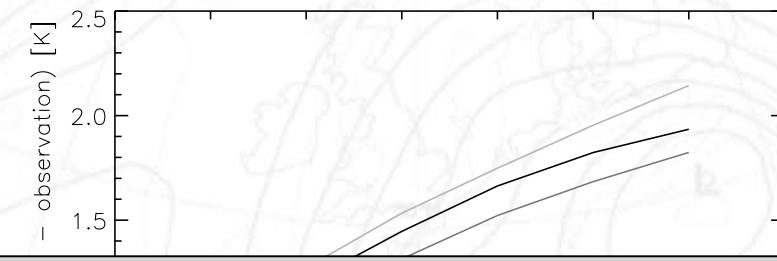
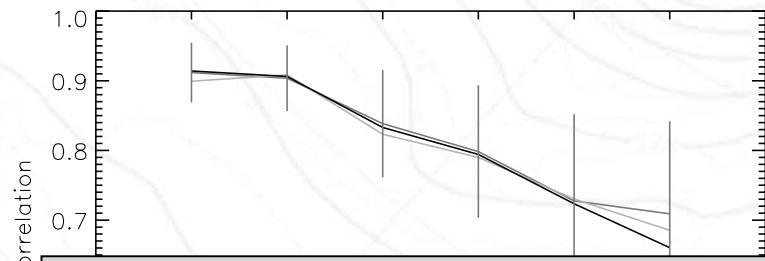
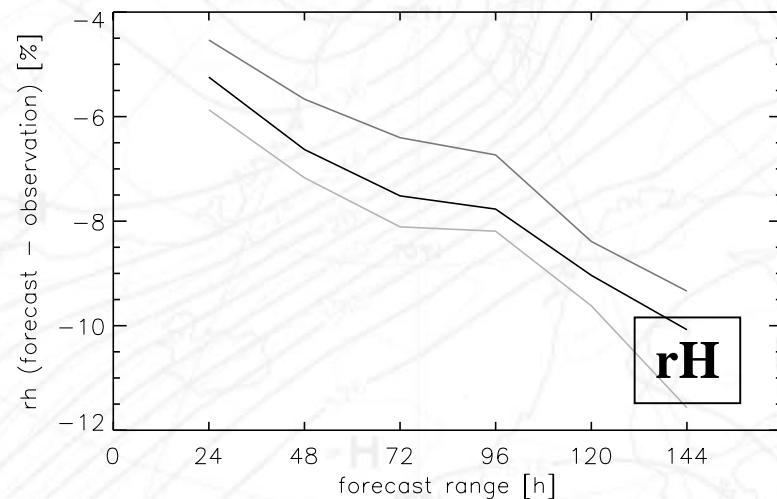


# Soil Moisture Assimilation over Land: Experiments with the TMI data set [Gao et al.]

correlation (observation / fc)



bias



The impact of the satellite data on the forecast quality (of screen level variables) is neutral (correlation). The biases obtained from the nudging experiment are slightly higher when compared against the OI and lower when compared against the OL.